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DISPOSAL OF SPENT BATTERIES AND THE
FEASIBILITY OF RECLAIMING THEIR
COMPONENTS

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Army Natick Development Center
Natick, Massachusetts

27 May 1975

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>Spent and new dry cell batteries were buried in loam and in sand, and in acidic and near neutral to slightly basic conditions. Water was poured periodically over the burial site and the leach was analyzed for heavy metal ion concentrations by means of atomic absorption spectroscopy.</p> <p>Test data and industry contact show that there is no serious pollution problem associated with the disposal of carbon-zinc dry cell batteries other than their bulk. The batteries should be disposed of along with other trash -See: Reverse-</p>		

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20. Abstract (Continued)

in sanitary land fills. When large quantities of batteries are discarded, they should be buried at a site that is well drained, above the ground water table, and in calcareous earth or in areas amended with lime.

Recycling of dry cell batteries was found to be economically unfeasible at this time.

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FOREWORD

Ecological concern over the practice of disposing of waste materials into the natural environment has led to the awareness that pollutants randomly added to the balance of nature can have profound effects.

Burying waste materials in the soil no longer is an acceptable mode of disposition of unusable material. Metals and metallic salts, in particular, are potential pollutants, especially if they are transposed to water sources. The toxicological ramifications implied by the presence of, particularly, heavy metal ions on natural processes are of immediate concern and require prior knowledge of what happens when materials are buried in the soil.

The Army's 1972 mission in pollution abatement was stated --"to develop practical systems needed to abate pollutants resulting from the manufacturing and use of material required for the protection, support and sustenance of the combat soldier both in garrison and field-type military operations. To achieve this goal, research, development and engineering studies that exploit both currently available and newly developed technology needed to engineer physical, chemical and biological pollution abatement treatment systems will be emphasized."

This study was conducted at the request of the Army Materiel Command to support the US Army Electronics Command requirement to determine the best available means of disposing of large quantities of spent dry cell batteries and/or methods for reclaiming some of the materials components. The work described was performed during the period from August 1972 - April 1974 under NDC project 1T062105A329-10 entitled "Organic Materials Research" and subsequently project No. 1T162105AH84-10 entitled "Pollution Abatement Studies." The study was performed in the Chemical Mechanisms Section, Textile Research and Engineering Division, Clothing and Personal Life Support Equipment Laboratory and was monitored by Mr. Leo Spano, Manager of the NDC Pollution Abatement Program.

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I. INTRODUCTION

Dry cell batteries used by the Army as a source of electrical energy are generally discarded without recharging, not unlike the typical civilian practice. Of the several types of dry cell batteries used, it is current Army practice to bury outdated and spent magnesium and zinc dry cell batteries, whereas mercury, lead and cadmium type dry cell batteries are usually salvaged for their constituent metals.^{a,b,c} Table I is illustrative of the quantities of magnesium and zinc type dry cell batteries purchased by the Army in a typical year, 1972. Since most (over 90%) of all batteries procured were of the carbon-zinc type, they were accordingly selected for the experiments to be described in this report, particularly in regards to the soil burial experiments.

II. BACKGROUND

Carbon-zinc dry cell batteries (Leclanche cells) are available in a variety of shapes, sizes and voltages.^d The voltage of the carbon-zinc cell is 1.5 volts; however, multiples of this may be obtained by connecting cells in series. Increased capacity may be achieved by connecting the cells in parallel. Both capacity and voltage may be increased in the same battery pack by including cells connected in parallel and series. Carbon-zinc batteries consist of a zinc cup anode and a centrally located carbon rod cathode around which is packed a paste, consisting of manganese dioxide, and the electrolyte, a mixture of aqueous ammonium chloride and zinc chloride. Materials such as starch and flour are added to thicken the mix along with carbon black to increase conductivity. Direct contact between the manganese dioxide and the zinc is prevented by use of plastic or cardboard liners. Thickening agents and outside steel jackets presently used in better grade batteries prevent the leakage of fluid from the depleted cell.

a. US Army Natick Laboratories, C&PLSEL, TR&ED Report No. 77, Progress Report No. 1, Pollution Abatement, November 1972.

b. US Army Natick Laboratories, C&PLSEL, TR&ED Report No. 85, Progress Report No. 2, Pollution Abatement Research on High Polymers and Miscellaneous Materials, July 1973.

c. Private conversations with ECOM personnel, June 1972 and February 1974.

d. Department of the Army Technical Manual TM-11-415, Primary Batteries (Dry and Reserve Types), August 1966.

TABLE 1

ARMY PROCUREMENT OF DRY CELL BATTERIES - 1972

<u>Stock Number</u>	<u>Item Description</u>	<u>Quantity Procured</u>
6135-120-1020	Battery, Dry, Type "D", 1 Terminal, Flat Surface. 1.5 Volts; Type No. BA-30, Max Wt. 4 oz(113g); 24 per pkg \$1.68/pkg. This is the standard flashlight battery.	4,250,000
6135-043-0021 (when supply exhausted use 6135-120-1030)	Battery, Dry, Type "AA", Single Voltage (Untapped) Cylindrical. 1.5 Volts; Diameter (D)-0.563 in (14mm); Height (H) 1.813 in (46mm); 1 Terminal, Flat Surface MIL-B-18, Type No. BA-58, Wt 0.6 oz (17g); \$0.06 each.	415,000
6135-120-1010	Battery; Dry, Type "C", Single Voltage (Untapped) Cylindrical. 1.5 Volts; D-1 in (25mm); H-1.750 in (44mm); 1 Terminal, Flat Surface, MIL-B-18, Type No. BA-42, Wt 2 oz (57g); \$0.09 each.	312,000
6135-050-3280	Battery, Dry, Type "F", Single Voltage (Untapped) Non-cylindrical, other than Socket Type Terminals. 6 Volts; Length (L) 2.625 in (67mm); Width (W) 2.625 in (67mm) H 3.875 in (98mm); 2 Terminals, Coil Spring, MIL-B-18, Type No. BA 200/U, Wt 1 lb, 8 oz (680 g); \$0.60 each.	132,000
6135-926-8322	Battery, Dry, Rectangular Shape. L- 9.500 in (241 mm); W-3.625 in (92mm); H-2.125 in (54mm); 5 Socket Type Terminals, 3 Live Contacts, 2 Dummy Contacts; P/O Radio Set Jetds, Type No. AN/PRC-25; MIL-B-18, Type No. BA-4386*, \$3.30 each.	130,000
6135-926-0845	Battery, Dry, Combination Packs. 7.5 Total Voltage; L-1.937 in (49mm); W or D-1.312 in (33mm); H-1.687 in (43mm); 1 Terminal, Socket Type, 4 Live Contacts; Jetds Type No. BA 399/U, \$0.80 each.	70,000
6135-935-8630 (use 6135-153- 0069)	Battery, Dry, BA-505 or BA-4505*, No Data, \$1.20 each.	24,000

*Batteries BA-4386 and BA-4505 are magnesium batteries. All other BA type of batteries are of the zinc variety.

III. EXPERIMENTAL PROCEDURES AND RESULTS

III-1. SOIL BURIAL

The major effort in this investigation has been expended in establishing two series of accelerated soil burial tests. In the first series, six cylindrical, polyethylene containers, nominal 29 gallon (110 liter) capacity, were partially filled with soil and batteries (see Figure 1). In container 1 (farthest from view), 36 pounds [16.4 kilograms (kg)] of new type "D" Eveready flashlight batteries [procured from the General Services Administration (GSA)] were interspersed among 145 pounds (65.9 kg) of loamy soil. In container 2, 40 pounds (18.2 kg) of various spent dry cell batteries received from the US Army Electronics Command (ECOM) (which we learned later were mercury batteries) were buried in 135 pounds (61.4 kg) of loamy soil. Container 3 had only loamy soil (control). Container 4 held 64 pounds (29.1 kg) of type "D" batteries and 163 pounds (74.1 kg) of sand. Container 5 had 40 pounds (18.2 kg) of mercury batteries and 140 pounds (63.6 kg) of sand. Container 6 (right center foreground) was a control and contained only sand. The containers were maintained at an ambient temperature of 80°F to 90°F (27°C to 32°C).

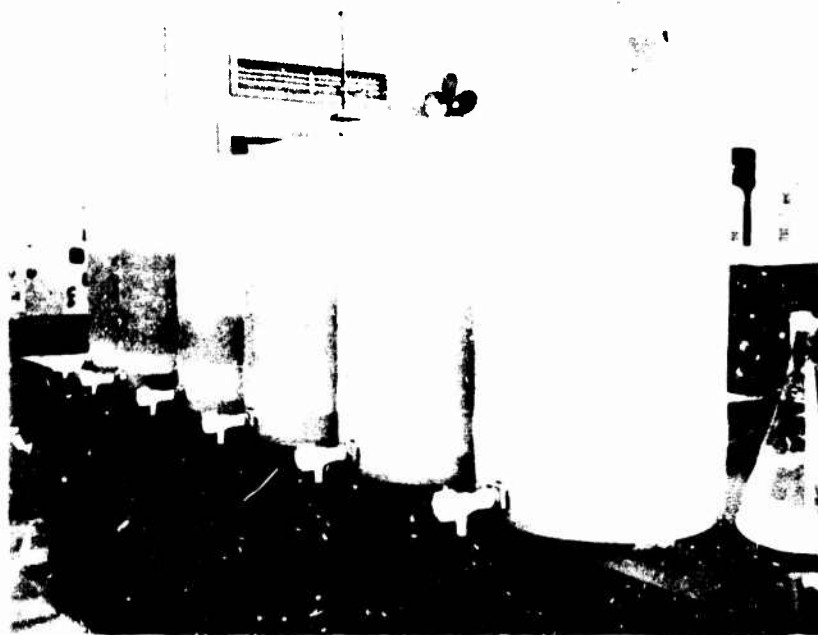


Figure 1. Filled containers used in accelerated soil burial test (1st series).

The second series was initiated approximately eight months after the first. In this series twelve, cylindrical, polyethylene containers, designated A through L, were filled (see Figure 2 and Table 2). Except for the control containers, each receptacle contained 60 pounds (27.3 kg) of new carbon-zinc dry cell batteries buried in 160 pounds (72.7 kg) of soil. A typical schematic of these containers can be seen in Figure 3 which depicts sample "D" as representative of this series. Sample "D" contained 56 pounds (25.5 kg) of punctured "D" (flashlight) batteries and 4 pounds (1.8 kg) of punct red "AA" (pen light) batteries buried in 160 pounds (72.7 kg) of loamy soil which had been previously mixed with 20 pounds (9.1 kg) of lime. Specific burial conditions in other containers are described with the analytical data (see Appendix A). Temperatures ranged from 70°F to 80°F (21°C to 27°C) for this series of experiments.

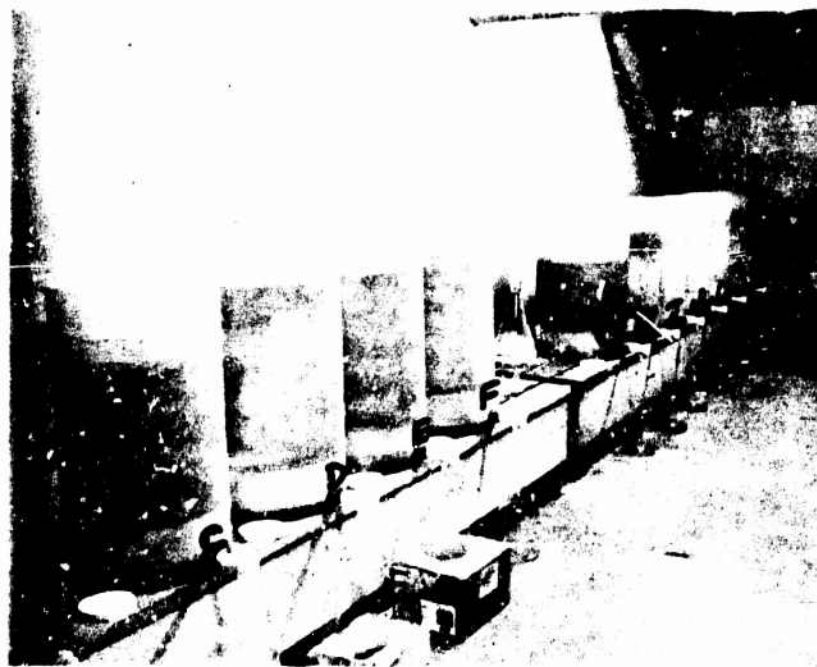


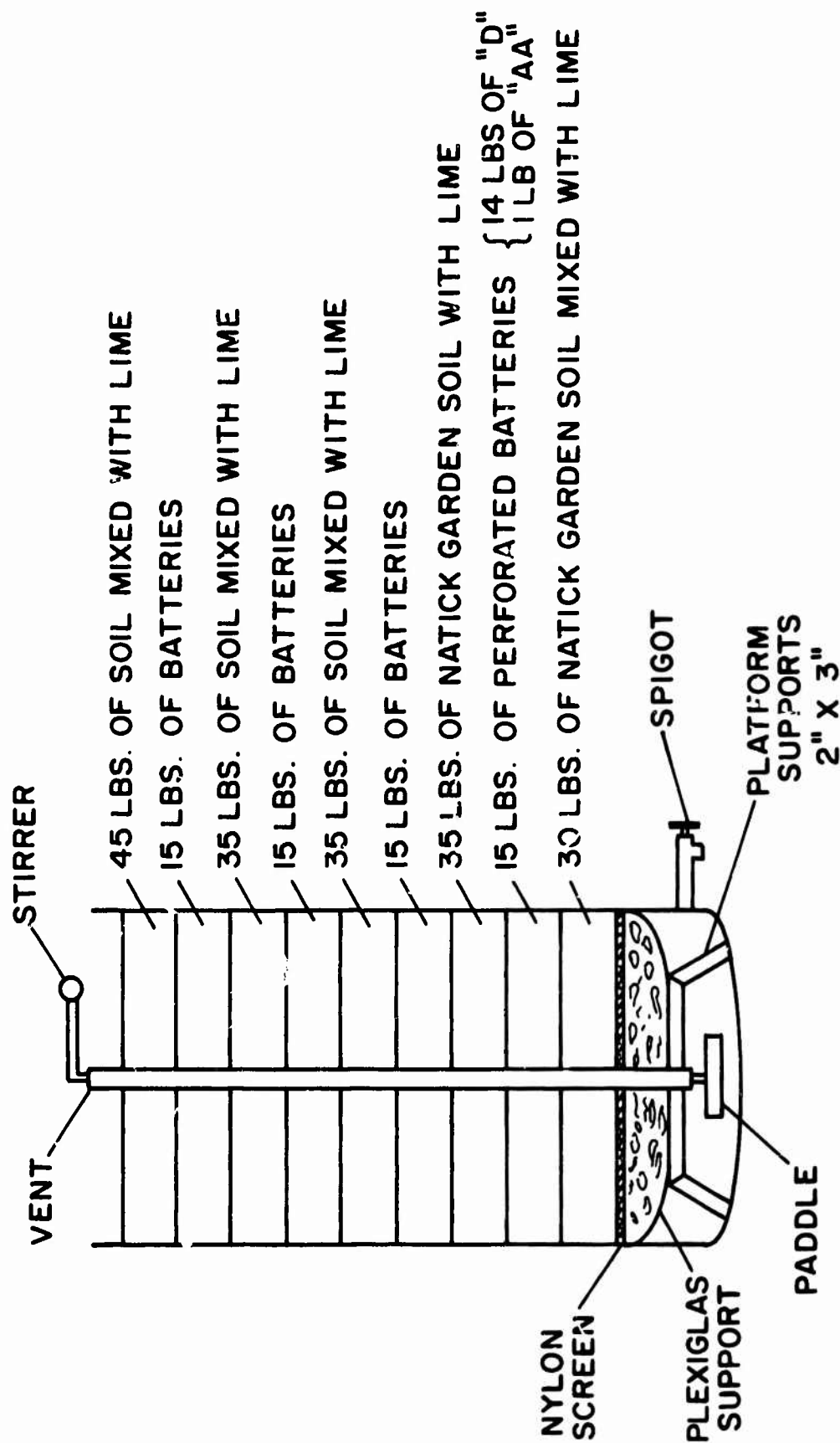
Figure 2. Some of the filled containers used in accelerated soil burial tests (second series).

TABLE 2
SOIL BURIAL CONDITIONS FOR BATTERIES IN SERIES 2*

<u>Sample Designation**</u>	<u>Soil Condition</u>	<u>Type of Soil</u>	<u>Condition of Batteries</u>
A	acidic (control)	loamy	none
B	acidic	loamy	perforated
C	basic (control)	loamy	none
D	basic	loamy	perforated
E	basic	loamy	whole
F	basic	loamy	perforated
G	acidic (control)	sandy	none
H	acidic	sandy	perforated
I	basic (control)	sandy	none
J	basic	sandy	perforated
K	basic	sandy	whole
L	basic	sandy	whole

*Acidic/loamy/whole condition and acidic/sandy/whole condition were covered in Series 1.

**Corresponds to soil container designation.



**FIG. 3 SCHEMATIC OF SAMPLE "D" USED IN AN
ACCELERATED SOIL BURIAL TEST.**

In summary, among the entire eighteen containers (both series), the following conditions were established:

(1) Batteries were buried in two different types of soil: loam and sand.

(2) The batteries were buried under acidic conditions, caused by the addition of tannic acid, and under near neutral to slightly basic conditions with the addition of lime. The purpose of the lime was to control pH and in this manner attempt to fix the heavy metals by regulating their solubility.^e

(3) Batteries were buried both intact and with holes drilled in them. The holes were introduced to accelerate the leaching of the contents.

III-2. SAMPLING AND TESTING

Four liters of distilled water having a pH between 5.6 and 6.4 were poured over the samples weekly to keep the soil moist. This is equivalent to one inch (25 mm) of rainfall per week. The water was allowed to permeate and percolate through the soil and to collect on the bottom of the container from which it was withdrawn through a drain (see Figure 4). For purposes of this report, the water that was withdrawn shall be referred to as the leachate. Initially, in the first series, the leachate was recycled weekly to determine the accumulated seepage of any contaminant from the buried batteries. During this period it was necessary to add fresh distilled water each week to compensate for evaporative or other losses. Approximately three months after the start of the first series of tests, the recycling of water was stopped and only fresh distilled water was used. In the second series only fresh distilled water was used.

Aliquot samples of the water effluent were withdrawn weekly and stored in the dark at room temperature. Approximately monthly, the accumulated water effluent samples of both series were analyzed by means of atomic absorption spectroscopy^f for zinc and manganese content. In addition, water effluent samples from the second series were tested for iron III content. Atomic absorption spectroscopy was chosen because the method is simple and rapid. There is relative freedom from interfering ions and this eliminates the need for extensive sample preparation and ion separation techniques. Because the flame oxidizes each metal to its highest valence state, only the total concentration of each metal is measured.

e. US Environmental Protection Agency, News of Environmental Research in Cincinnati, Ohio, Advanced Waste Treatment, May 31, 1973.

f. APHA, AWWA, WPCF, Standard Methods for the Examination of Water and Wastewater, 13th Edition, 1971.



Figure 4. Withdrawing water for analyses.

III-3. RESULTS AND DISCUSSION

The analyses of water effluents obtained in the first series of accelerated soil burial tests continued over a period of fourteen months. The results are found in Tables 3-8 (Appendix A). The data indicated that six months passed before any indication of battery deterioration occurred. This is illustrated in Chart 1 which is representative of the carbon-zinc batteries tested in both types of soil. In Chart 1, the concentration of zinc and manganese detected in the water effluent of sample No. 1 is plotted against time of burial. The upper plot shows that initially 4 ppm of manganese was present in the soil. With the addition of new distilled water the manganese content was lowered. After 30 weeks, the manganese content in the water effluent began to increase due to the manganese dioxide leaching from the batteries. The lower plot of Chart 1 shows that initially no zinc was detected in the effluent. Six months passed before even a sub-trace amount (less than 1 ppm) of zinc was detected. Both curves together indicate that after 14 months the concentrations were still low, 10 ppm for zinc and 18 ppm of manganese, but were increasing rapidly, indicating that the batteries were deteriorating rapidly.

Analyses of water effluents obtained in the second series continued for six months. The results are found in Tables 9-20 (Appendix A) and Charts 2-9. The data indicate that the use of lime tends to fix the heavy metals; that is, the metals are released into the leachate at a slower rate under basic conditions than in acidic conditions. An example of this is shown in Chart 2 for zinc, where the sample B plot represents 60 pounds (27.3 kg) of perforated carbon-zinc batteries buried in an acidic condition and the sample D plot represents 60 pounds (27.3 kg) of perforated batteries buried in near neutral condition. In both samples the batteries were buried in loamy soil. Together, the plots show that in an acidic condition over 4,000 ppm of zinc were detected in the effluent, whereas the highest measured concentration of zinc in the more basic condition was 68 ppm. Similar results are shown in Chart 3 for manganese and Chart 4 for iron III.

The fixation of the heavy metal ions occurred in both loamy soil (Charts 2-4) and in sandy soil (Charts 5-7). The results also show that sandy soil is less adsorptive (Charts 8 and 9). This is expected because it offers less resistance to the flow of the water carrying the zinc and manganese ions than does the loamy soil, and it has different surface and particle characteristics.

Simultaneously while conducting our own experiments, contact was established with Union Carbide Corporation, New York, NY 10017, and with National Electrical Manufacturers Association (NEMA), Washington, DC 20036, regarding their experiences with the battery disposal problem. It was learned that both institutions have carried on extensive studies which indicate that used batteries can be safely disposed of in approved sanitary landfill.

CHART 1. ATOMIC ABSORPTION RESULTS FOR SAMPLE NO. 1

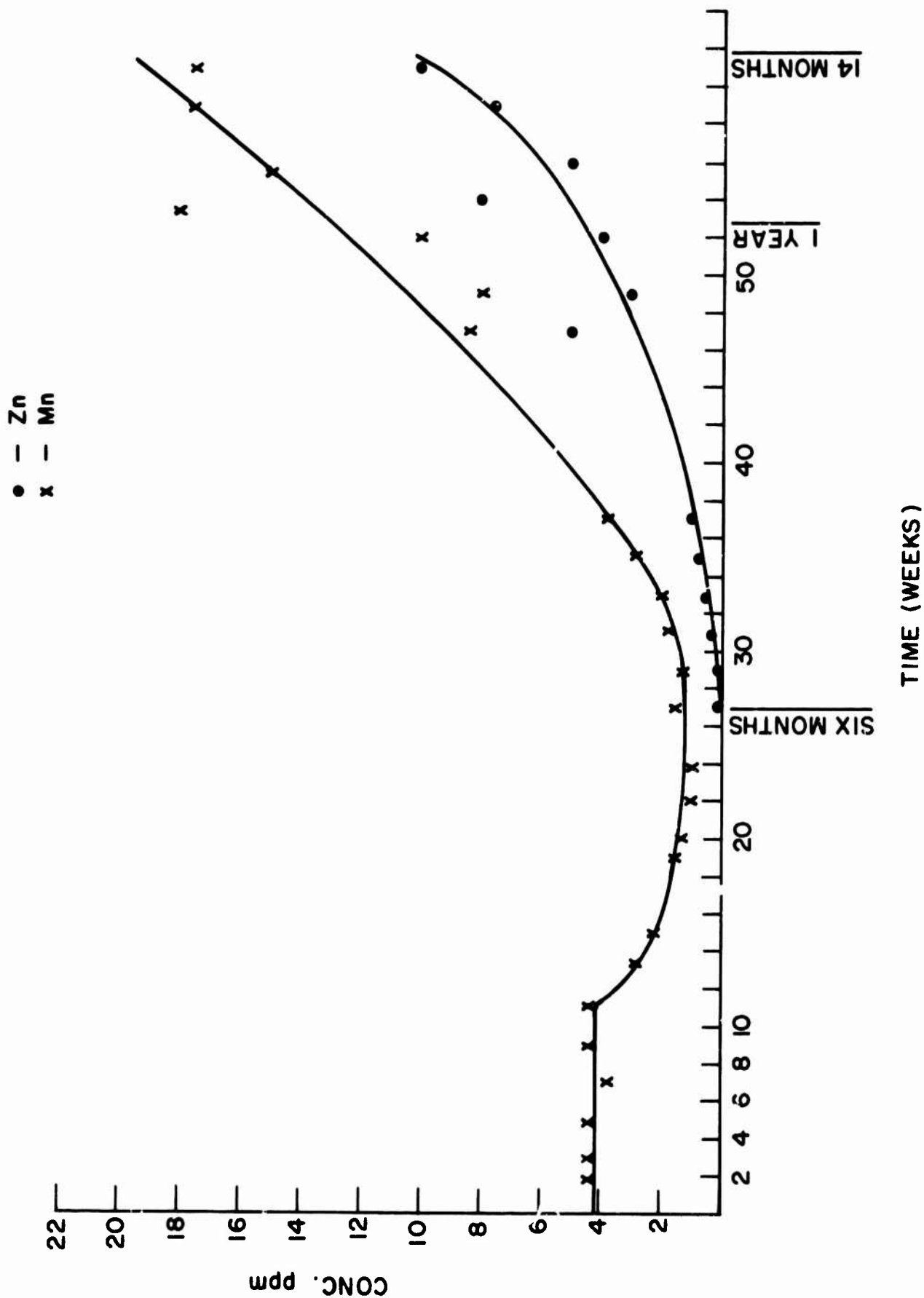


CHART 2. COMPARISON OF ATOMIC ABSORPTION DATA
FOR ZINC UNDER ACIDIC AND BASIC
CONDITIONS (GARDEN SOIL)

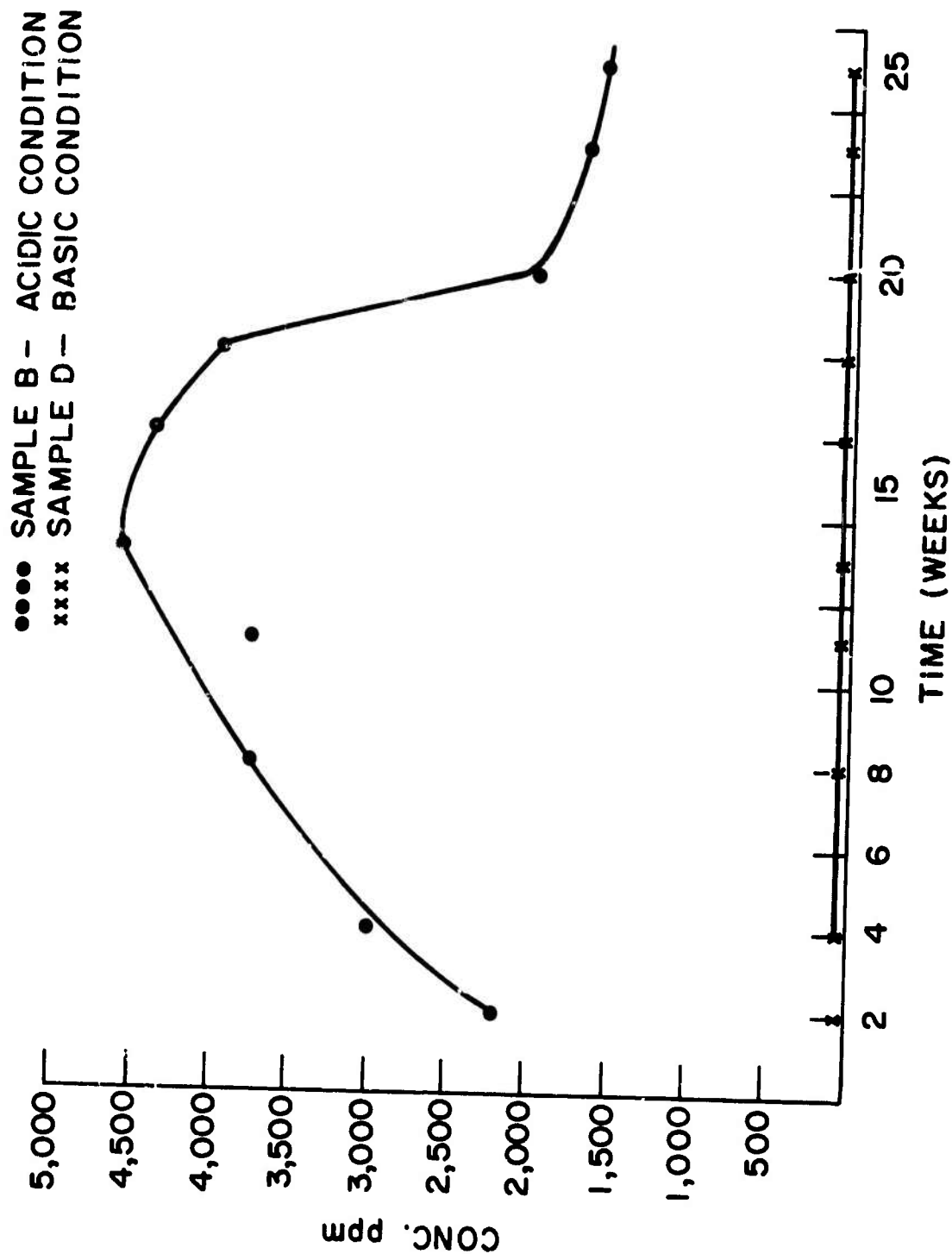


CHART 3. COMPARISON OF ATOMIC ABSORPTION DATA FOR
MANGANESE UNDER ACIDIC AND BASIC
CONDITIONS (GARDEN SOIL)

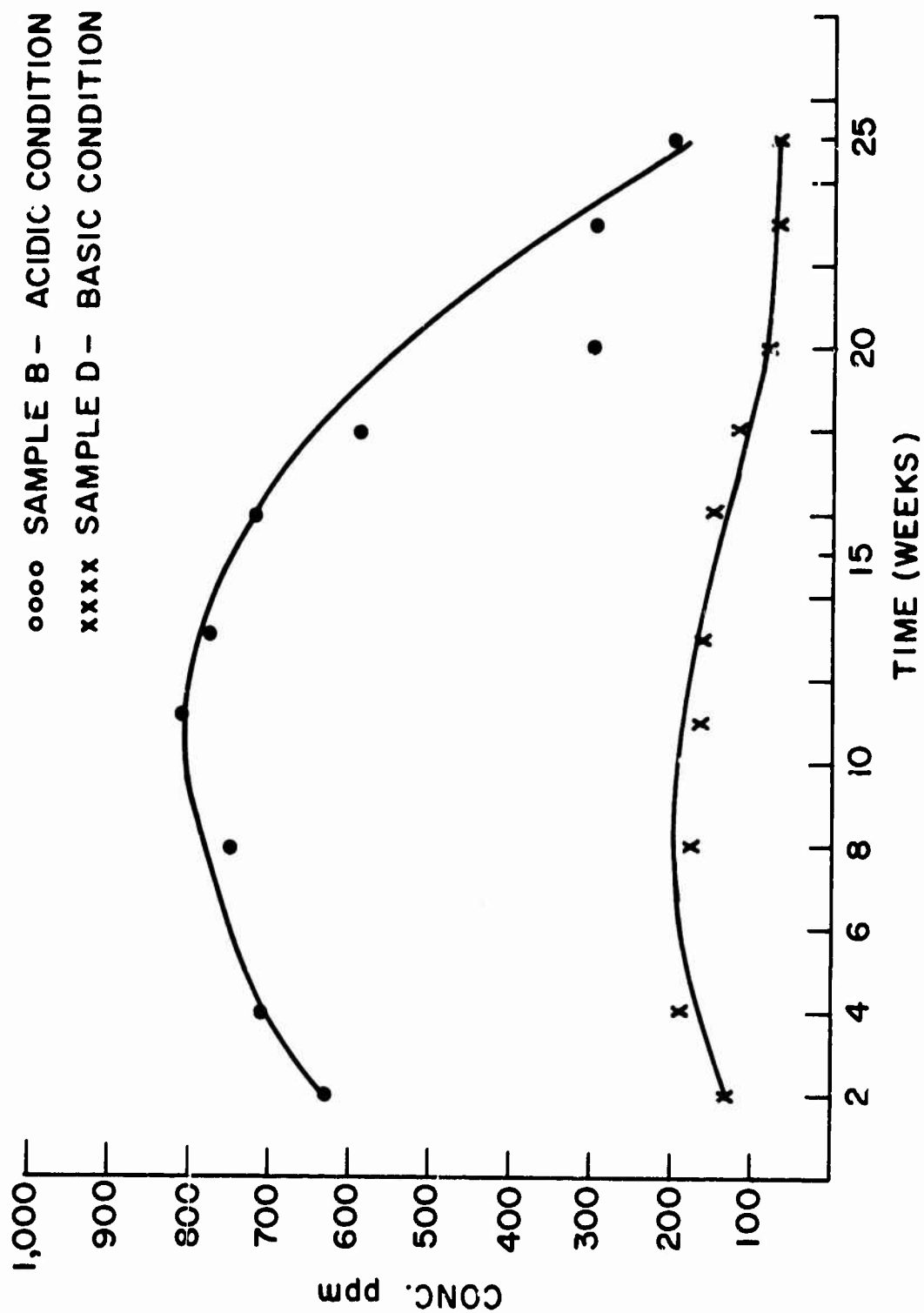


CHART 4. COMPARISON OF ATOMIC ABSORPTION DATA FOR
IRON (Fe^{+3}) UNDER ACIDIC AND BASIC
CONDITIONS (GARDEN SOIL)

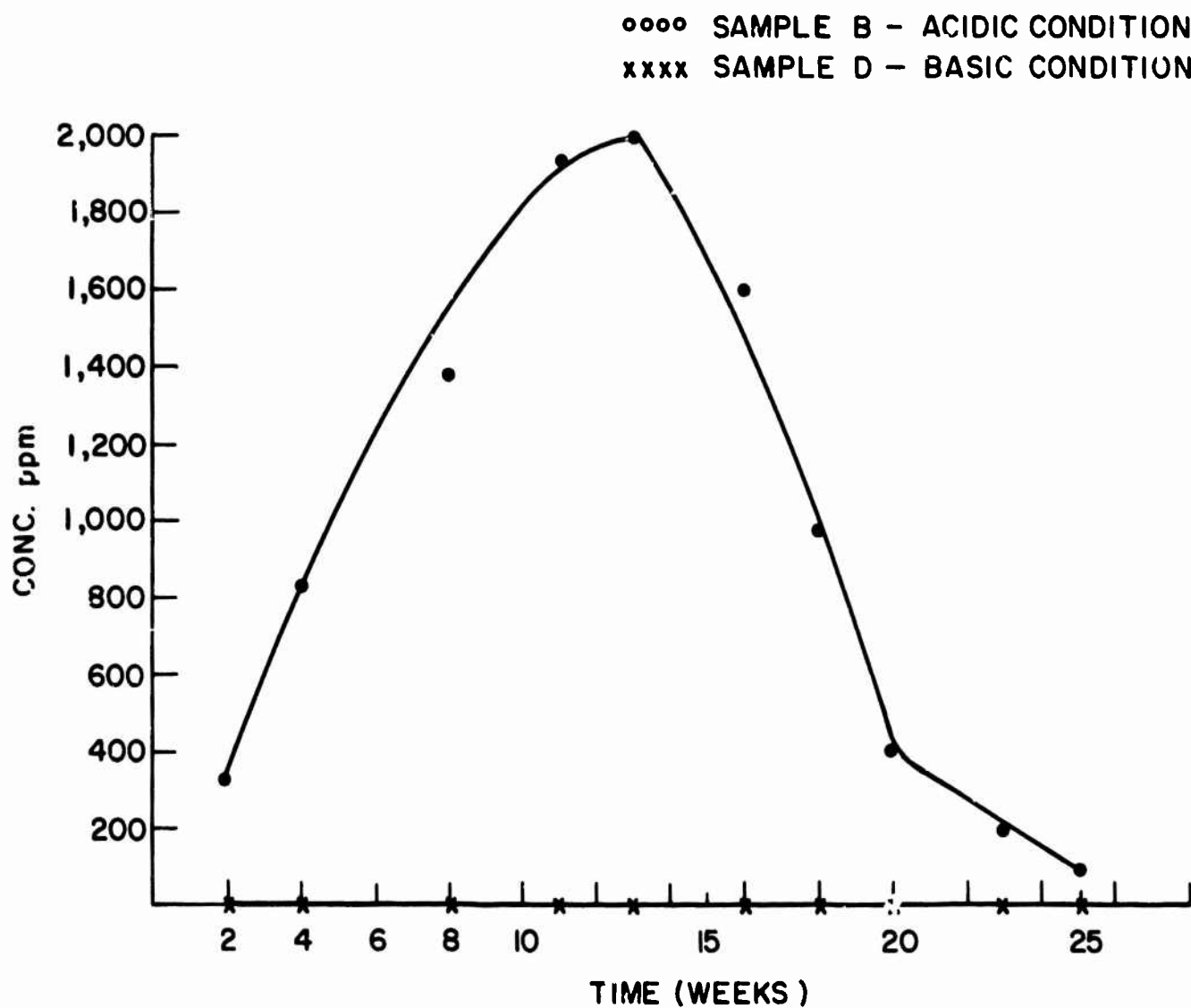


CHART 5. COMPARISON OF ATOMIC ABSORPTION DATA
FOR ZINC UNDER ACIDIC AND BASIC
CONDITIONS (SAND)

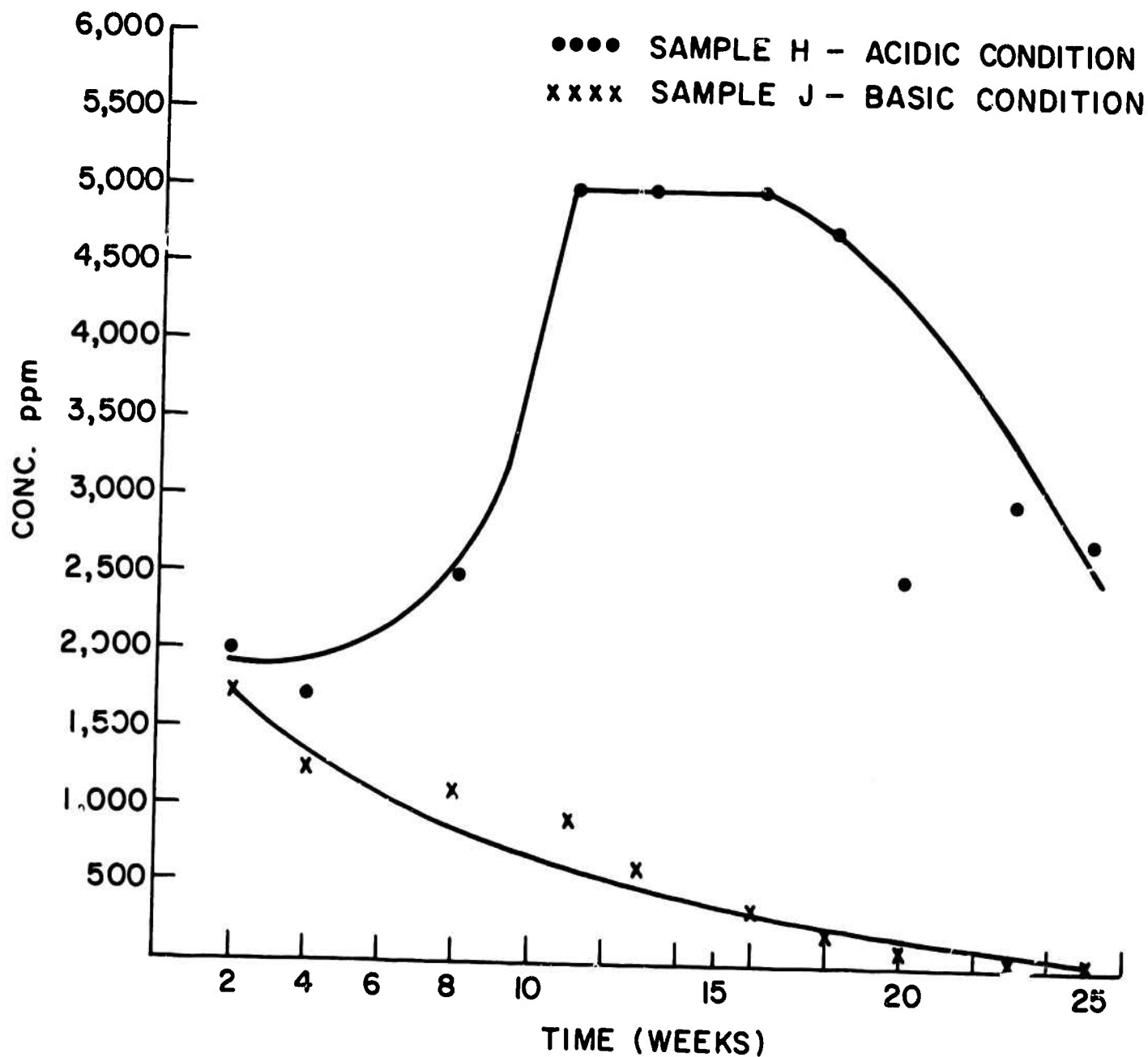


CHART 6. COMPARISON OF ATOMIC ABSORPTION DATA
FOR MANGANESE UNDER ACIDIC AND BASIC
CONDITIONS (SAND)

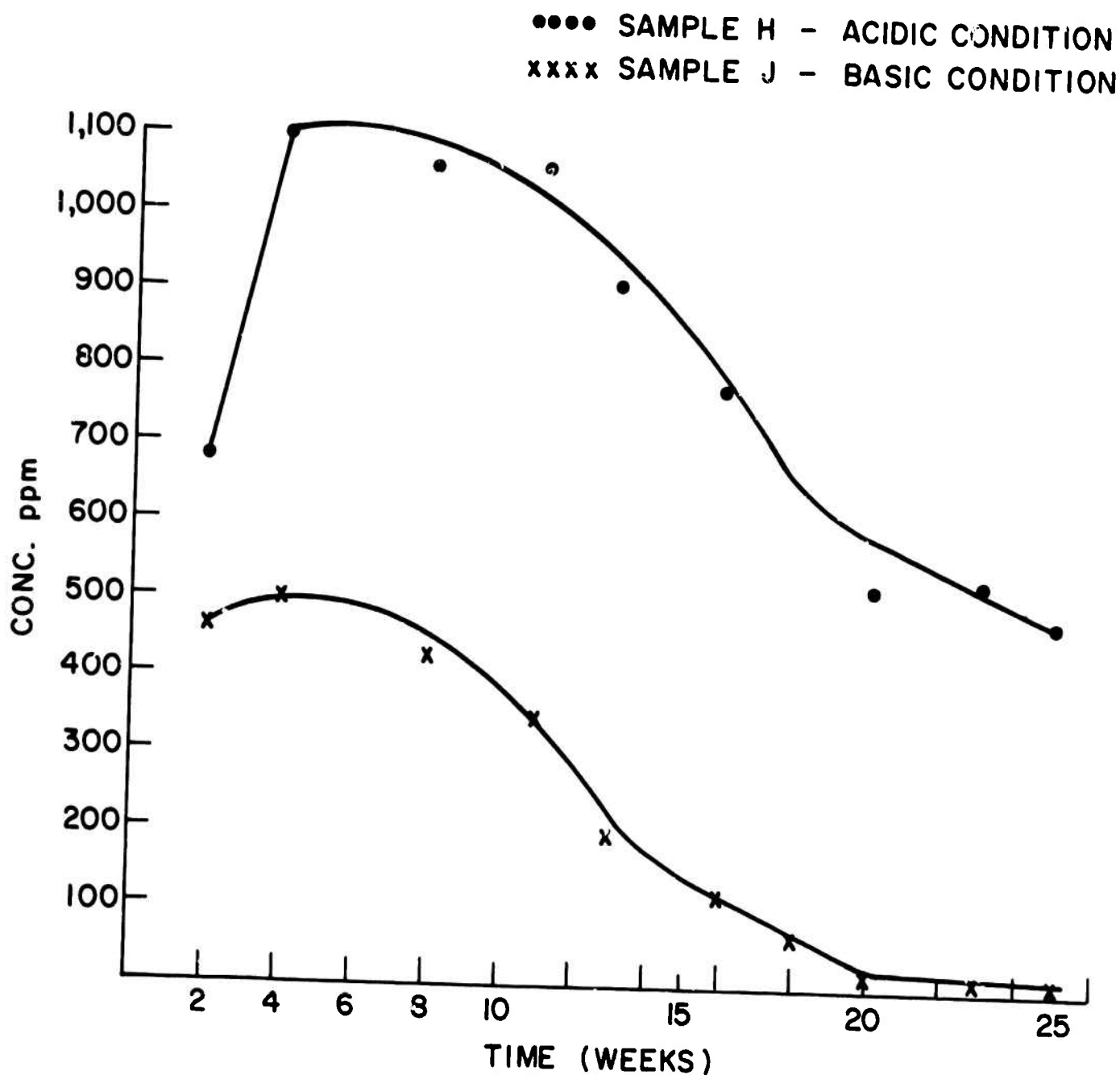


CHART 7. COMPARISON OF ATOMIC ABSORPTION DATA
FOR IRON (Fe^{+3}) UNDER ACIDIC AND BASIC
CONDITIONS (SAND)

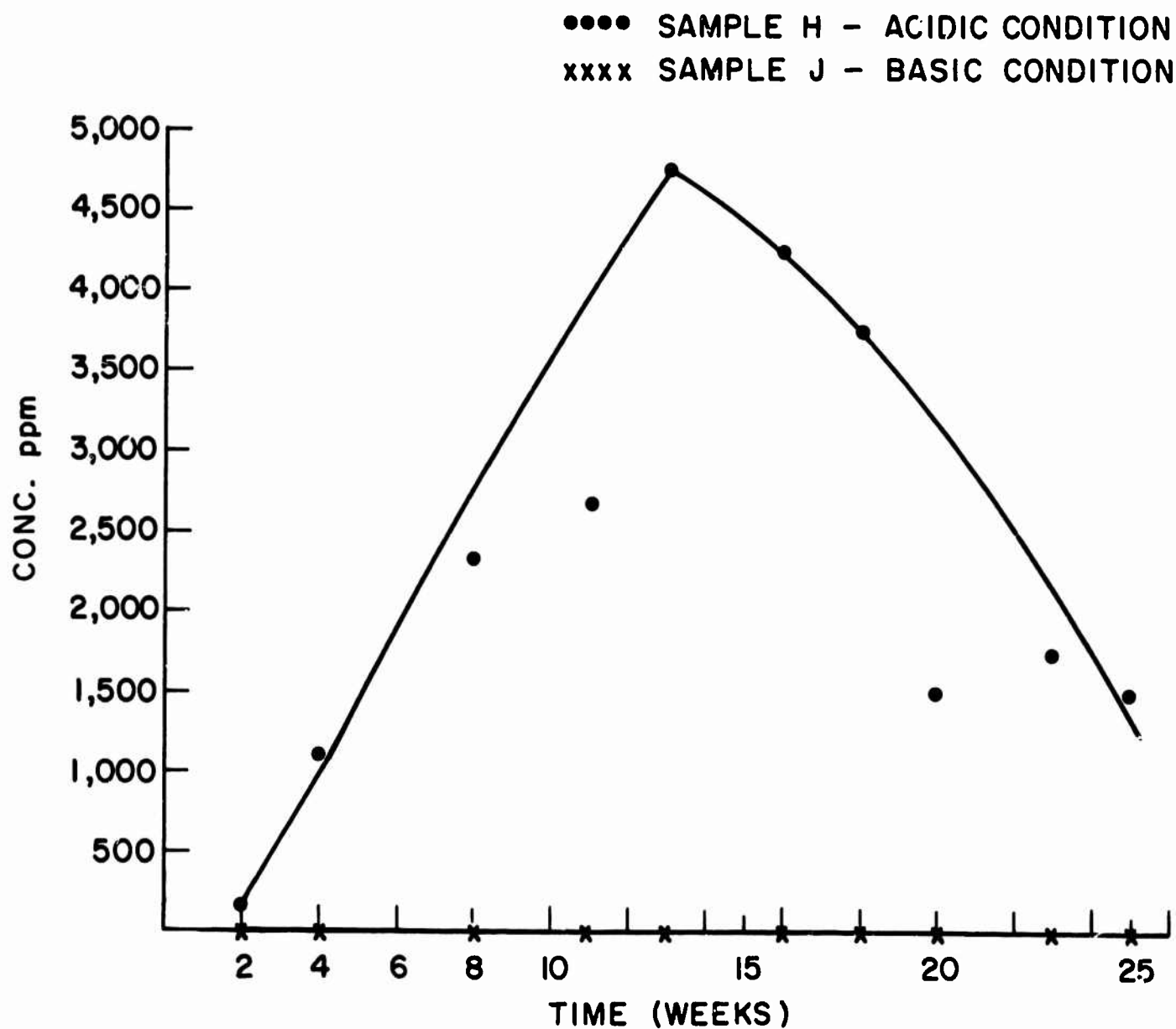


CHART 8. COMPARISON OF ATOMIC ABSORPTION DATA
FOR ZINC UNDER NEUTRAL TO
BASIC CONDITIONS

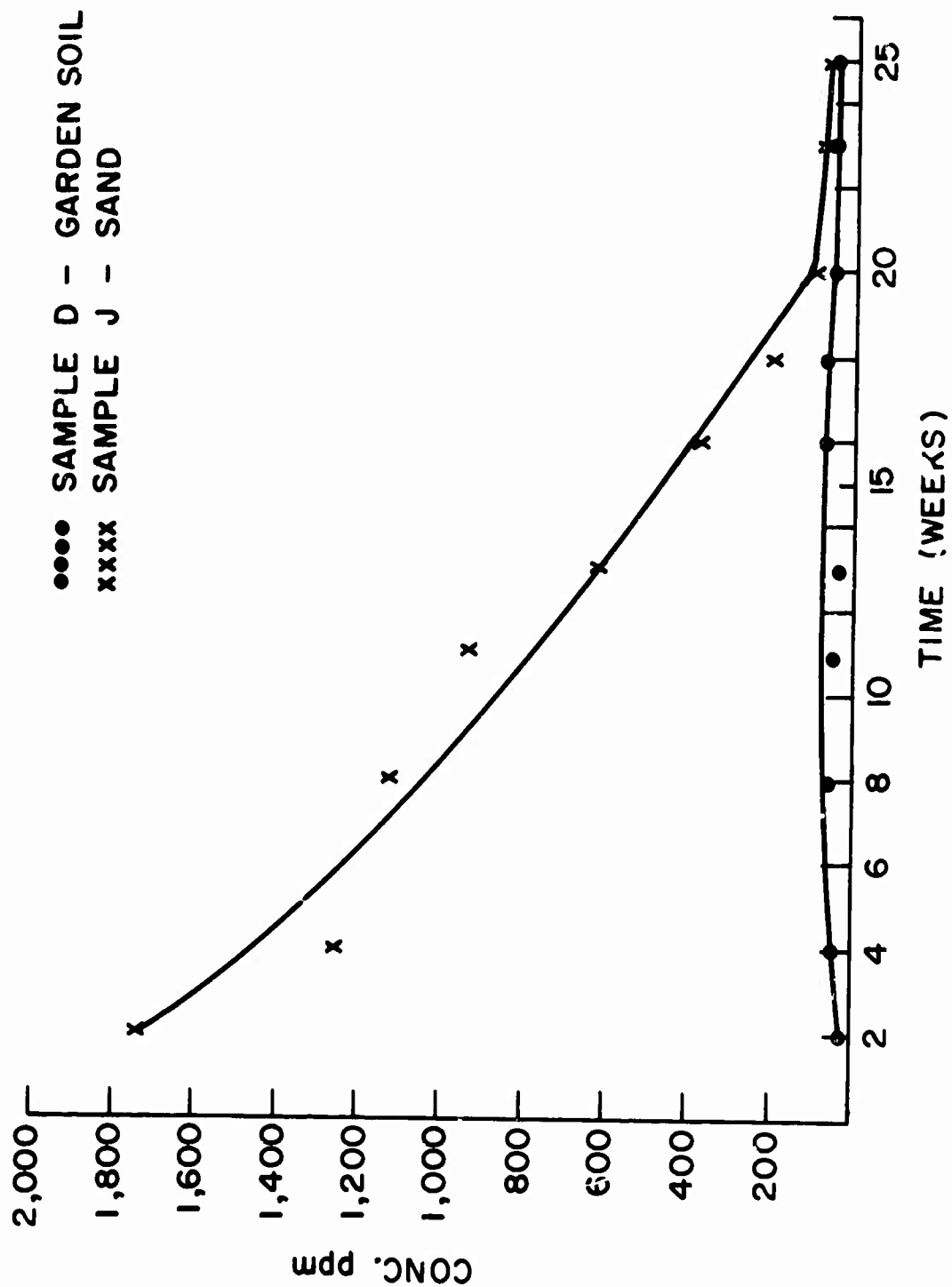
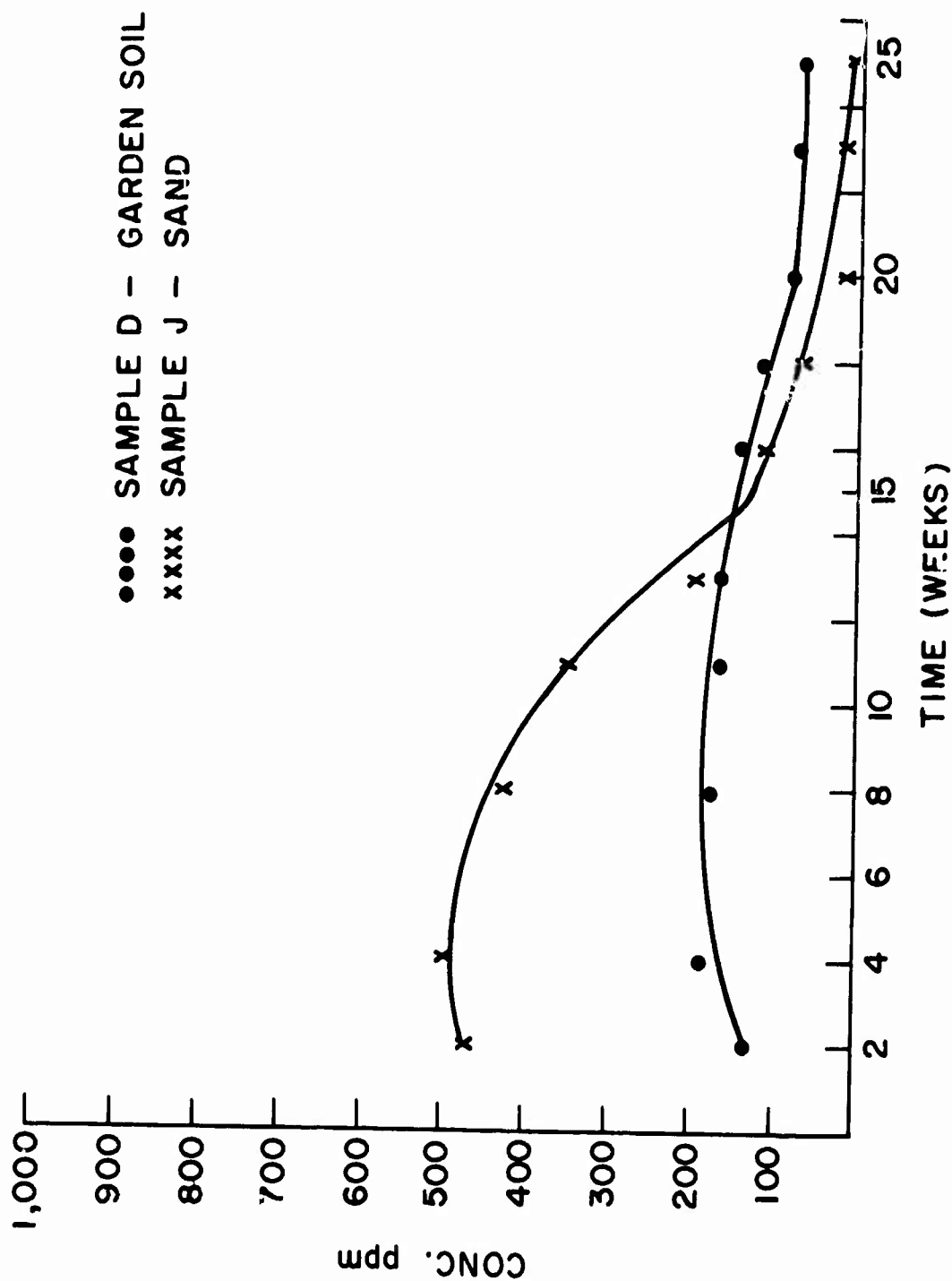


CHART 9. COMPARISON OF ATOMIC ABSORPTION DATA
FOR MANGANESE UNDER NEUTRAL TO
BASIC CONDITIONS



However, they caution that batteries discarded in bulk should not be incinerated or dumped into lakes or streams. Reports on their findings are expected to be available for distribution in the near future. The Illinois Institute of Technology Research Institute (IITRI), Chicago, Illinois 60616, conducted the research for NEMA. It has been reported² that IITRI results show that clay material greatly retards the migration of heavy metals and that sand or gravel type soils are less adsorptive and offer less resistance to water flow. These results agree with NDC findings. It was also reported that the concentration of metals in ground water in any soil decreases with distance from the source.

The tests conducted at NDC represent extremely severe effluent conditions. The water samples were obtained not more than a foot from the concentrated source of contamination. The concentration of metal ions was effectively reduced in these samples by passage through basic soil. Therefore, it can be safely assumed that if the same samples were analyzed after passage through several hundred feet of soil, they would show very low concentrations of the heavy metals.

III-4. RECYCLING COMPONENTS OF DRY CELL BATTERIES

Union Carbide Corporation indicated that extensive study has been made by the Industry, and they found that recycling for the metals in carbon-zinc batteries is uneconomical. A similar opinion was received from the Bureau of Mines, United States Department of the Interior, Washington, DC 20240. In their opinion, the market for expired carbon-zinc batteries is incapable of bearing the transportation costs involved in assembling the batteries at reprocessing points. This is due mostly to the low market value for scrap zinc and the existing abundance of more than 200,000 tons (180,000 megagrams) per year of recycleable zinc from sources such as automobile parts and steel smelter flue dust.

In response to a suggestion by this investigator concerning the disposal of carbon-zinc dry cell batteries in abandoned coal mines, the Bureau had the following opinion. They believed that the potential economic benefit from accumulation of base metal in coal mines would be more than offset by the acidic conditions that prevail in the mines which would tend to promote dissolution and removal of the zinc with probable serious contamination of ground water. They considered that the safest method for the disposal of individual dry cell batteries would be disposal at the time and place they expire. Disposal in other wastes would adequately preclude the accumulation of harmful concentrations of decomposition products.

² Private communication.

An unsolicited proposal for primary battery recycling was received from Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830. The proposal outlines the potential for recovering mercury, zinc, manganese, and carbon electrodes from dry batteries. The main premise of their proposal was the recovery of a large fraction of the mercury from mercury batteries. The relatively high percentage of mercury (18 to 38%) in the mercury cell and the relatively high price of mercury added an economic incentive for the recycling of mercury.

NDRC contacted Oak Ridge National Laboratory to discuss the preparation of a related proposal with a scope based only on the recycling of dry cell batteries for the recovery of zinc, manganese and the carbon rods. Oak Ridge indicated that presently there is no strong economic incentive to recycle dry cell batteries other than the mercury battery; this statement has been made in spite of the fact that the average carbon-zinc battery contains many times more zinc than the average commercial zinc ore, as well as a relatively high percentage of manganese. To attract interest in recycling batteries to recover these components, the economic problems associated with guaranteed supply, collection, and transportation would have to be solved. Assuming these problems could be surmounted, Oak Ridge indicated, at least in theory, that the carbon electrodes could also be recovered and reused. In reality, it was learned that Industry did not believe this was practical because the carbon electrodes are so cheap and easy to manufacture. Secondly, the wide variety of sizes and shapes of dry cells would overly complicate the technical problems of trying to recover the carbon electrodes intact.

It was estimated, based on an annual Army procurement of 5,000,000 carbon-zinc dry cell batteries, that the maximum possible value of recoverable products would be less than \$100,000. To consider recycling of dry cell batteries a much larger usage would be required to allow the reprocessor to take advantage of the economics of scale.

Though there are presently good ecological reasons for recycling batteries, the Army situation for recycling them appears to be economically and technologically marginal at best. Because of the marginal nature of this venture, it was decided not to expend any funds in this area.

IV. CONCLUSIONS

1. There is no serious pollution problem associated with the disposal of carbon-zinc dry cell batteries other than their bulk.
2. The recycling of these batteries is economically unfeasible at this time.

V. RECOMMENDATIONS

It is recommended that carbon-zinc dry cell batteries be discarded individually, after use, at the time and place they expire. The batteries should be disposed of along with other trash in sanitary land fills. When large amounts of batteries are to be discarded, as from a warehouse, they should be buried at a site that is well drained, above the ground water table, and in calcareous earth or in areas amended with lime. Loam or garden soil is preferable over sand, and clay would probably be best for such burial.

VI. ACKNOWLEDGEMENT

The author gratefully acknowledges the assistance of Mr. Stephen Swift of the Analytical Group, Food Chemistry Division, Food Laboratory, in performing the atomic absorption spectroscopy tests, and Dr. Richard N. Macnair, Group Leader, Fibrous and Organic Materials Group, in providing guidance and editorial review of this report.

APPENDIX A
TABLES 3-20 - ATOMIC ABSORPTION RESULTS

TABLE 3

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 1

(Sample No. 1 contained 36 pounds (16.4 kg) of type "D" flashlight batteries interspersed among 145 pounds (65.9 kg) of loamy soil.)

Elapsed Time (Weeks)	Concentrations		pH of Sample	pH of Distilled Water
	Zn (ppm)	Mn (ppm)		
2	0	4.3	6.3	6.0
3	0	4.4	6.0	6.0
5	0	4.4	6.3	5.5
7	0	3.8	6.1	5.5
9	0	4.3	6.4	5.8
11	0	4.2	6.2	5.8
13	0	2.8	6.6	6.0
15	0	2.3	6.4	6.0
19	0	1.6	6.7	6.3
20	0	1.4	6.5	6.3
22	0	1.1	6.4	5.4
24	0	1.1	6.3	5.4
27	0.1	1.5	5.8	5.0
29	0.15	1.4	5.9	6.0
31	0.3	1.7	5.2	5.6
33	0.5	2.0	4.9	5.6
35	0.7	2.9	4.3	6.0
37	1.0	3.8	4.4	6.0
47	5.0	8.4	3.9	5.6
49	3.0	8.0	3.7	5.6
52	4.0	10.0	4.1	5.9
54	8.0	18.0	3.8	6.4
56	5.0	15.0	3.7	6.4
59	7.5	17.5	3.8	7.3
61	10.0	17.5	3.8	6.4

TABLE 4

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 2

(Sample No. 2 contained 40 pounds (18.2 kg) of various mercury dry cell batteries buried in 135 pounds (61.4 kg) of loamy soil.)

Elapsed Time (Weeks)	Concentrations		pH of Sample
	Zn (ppm)	Mn (ppm)	
2	0	5.9	6.0
3	0	7.0	5.9
5	0	7.5	6.7
7	0	7.5	6.5
9	0	5.9	6.4
11	0	5.3	6.7
13	0	4.2	7.0
15	0	2.8	7.1
19	0	1.4	7.2
20	0	1.2	7.5
22	0	1.0	7.1
24	0	0.7	7.0
27	0	0.5	6.8
29	0	0.3	7.0
31	0	0.4	7.0
33	0	0.3	6.7
35	0	0.1	7.8
37	0	0.1	7.1
47	0	0.1	7.6
49	0	0.2	8.0
52	0	0.1	7.1
54	0	0.2	7.4
56	0	0.1	7.8
59	0.1	0.1	7.8
61	0	0.1	7.8

TABLE 5

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 3

(Sample No. 3 was a control and contained only loamy soil.)

Elapsed Time (Weeks)	Concentrations		pH of Sample
	Zn (ppm)	Mn (ppm)	
2	0	1.5	6.0
3	0	1.1	5.6
5	0	0.7	6.2
7	0	0.5	5.7
9	0	0.4	5.7
11	0	0.3	5.7
13	0	0.2	6.1
15	0	0.2	6.2
19	0	0.3	6.4
20	0	0.3	6.2
22	0	0.2	5.7
24	0	0.2	5.3
27	0	0.3	5.7
29	0	0.2	5.8
31	0	0.4	5.9
33	0	0.3	5.2
35	0	0.1	6.3
37	0	0.1	5.7
47	0	0.1	5.8
49	0	0	6.2
52	0	0.1	5.9
54	0	0	6.5
56	0	0	7.0
59	0	0	6.7
61	0	0	6.7

TABLE 6

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 4

(Sample No. 4 had 64 pounds (29.1 kg) of type "D" batteries and 163 pounds (74.1 kg) of sand [obtained from the Natick Town Dump] of the type used for sanitary land fill.)

Elapsed Time (Weeks)	Concentrations		pH of Sample
	Zn (ppm)	Mn (ppm)	
2	0	11.4	5.2
3	0	9.8	5.5
5	0	4.8	6.7
7	0	2.4	6.8
9	0	1.3	6.7
11	0	0.9	6.6
13	0	0.6	7.2
15	0	0.7	7.2
19	0	0.7	7.4
20	0	0.5	7.9
22	0	0.6	7.4
24	0	0.6	7.4
27	0	1.3	7.3
29	0.1	1.9	7.3
31	0.4	2.6	6.2
33	0.7	4.5	6.3
35	2.1	6.3	4.4
37	3.0	9.0	5.0
47	8.0	18.0	5.2
49	10.0	22.0	6.3
52	10.0	20.0	6.8
54	10.0	15.0	5.0
56	7.5	10.0	7.0
59	10.0	10.0	6.2
61	10.0	10.0	6.4

TABLE 7

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 5

(Sample No. 5 contained 40 pounds (18.2 kg) of mercury batteries buried in 140 pounds (63.6 kg) of sand.)

Elapsed Time (Weeks)	Concentrations		pH of Sample
	Zn (ppm)	Mn (ppm)	
2	0	9.5	6.5
3	0	9.1	6.5
5	0	5.7	7.0
7	0	3.1	7.3
9	0	1.5	7.3
11	0	1.1	7.4
13	0	0.8	7.7
15	0	0.9	7.8
19	0	1.2	8.0
20	0	0.9	8.2
22	0	0.6	8.2
24	0	0.5	8.0
27	0	0.3	8.0
29	0	0.2	8.3
31	0	0.5	8.2
33	0	0.3	8.1
35	0	0.1	8.6
37	0	0.1	8.5
47	0	0.1	8.4
49	0	0	8.7
52	0	0	8.6
54	0	0	9.1
56	0	0	9.0
59	0	0	8.7
61	0	0	8.8

TABLE 8

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE NO. 6

(Sample No. 6 was a control and contained only sand.)

Elapsed Time (Weeks)	Concentrations		pH of Sample
	Zn (ppm)	Mn (ppm)	
2	0	6.8	5.2
3	0	6.5	5.4
5	0	6.4	6.5
7	0	6.1	6.2
9	0	5.8	6.2
11	0	5.6	6.2
13	0	4.1	6.5
15	0	2.5	6.7
19	0	2.0	6.4
20	0	1.8	6.8
22	0	1.4	6.7
24	0	1.4	6.6
27	0	0.9	6.8
29	0	0.7	6.8
31	0	0.8	6.8
33	0	0.6	6.2
35	0	0.1	7.0
37	0	0.1	6.6
47	0	0.1	7.0
49	0	0	6.6
52	0	0	6.5
54	0	0	6.9
56	0	0	6.4
59	0	0	6.3
61	0	0	6.4

TABLE 3

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE A

(Sample A is an acid control and contains 4 pounds (1.8 kg) of tannic acid in 160 pounds (72.7 kg) of loamy soil.)

Elapsed Time (Weeks)	Concentrations			pH of Sample	pH of Distilled Water
	Zn (ppm)	Mn (ppm)	Fe (ppm)		
2	2.0	66	134	3.8	6.0
4	4.0	86	280	3.7	6.0
8	5.0	87.5	335	3.8	5.7
11	2.5	77	360	4.0	5.6
13	1.9	50	270	4.8	5.6
16	1.4	45	270	5.1	5.9
18	0.4	40	180	6.8	6.5
20	0	5.0	15	5.2	6.3
23	0.1	5.0	10	6.1	6.4
25	0.1	4.5	15	5.8	6.4

TABLE 10

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE B

(Sample B represents perforated carbon-zinc batteries buried in an acid condition. 56 pounds (25.5 kg) of perforated "D" batteries and 4 pounds (1.8 kg) of perforated "AA" batteries were buried in 160 pounds (72.7 kg) of loamy soil mixed with 5 pounds (2.3 kg) of tannic acid.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	2,200	630	330	3.5
4	2,000	705	830	3.4
8	3,750	750	1,375	3.4
11	3,750	812	1,938	3.1
13	4,600	780	2,000	3.3
16	4,400	720	1,600	3.3
18	4,000	590	980	3.3
20	2,000	300	410	3.2
23	1,700	300	200	3.4
25	1,600	200	100	3.3

TABLE 11

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE C

(Sample C was a base control and contained 20 pounds (9.1 kg) of lime in 160 pounds (72.7 kg) of loamy soil.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	0	0.5	0.2	7.1
4	0	0.5	0.1	6.7
8	0	0.6	0	6.5
11	0	0.8	0	7.9
13	0	0.8	0.2	6.9
16	0	0.7	0.2	7.0
18	0.2	0.9	0	7.8
20	0.9	1.7	0	7.6
23	0	0.8	0.2	7.0
25	0	1.1	0.4	7.2

TABLE 12

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE D

(Sample D contained 60 pounds (27.3 kg) of perforated batteries in 160 pounds (72.7 kg) of loamy soil which had been previously mixed with 20 pounds (9.1 kg) of lime.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	24	127	0.3	6.0
4	45	188	0.2	6.1
8	52.5	178	0.3	5.8
11	45	170	0	6.7
13	35	165	2.5	6.1
16	38	143	2.5	6.2
18	60	118	0	6.7
20	40	82.5	0.1	6.6
23	37.5	75	0.1	6.4
25	37.5	72.5	0.1	6.4

TABLE 13

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE E

(Sample E had 60 pounds (27.3 kg) of batteries buried in 160 pounds (72.7 kg) of loamy soil mixed with 20 pounds (9.1 kg) of lime.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	15	1.7	4.2	6.9
4	17.5	4.1	6.0	6.6
8	21	6.0	7.0	6.4
11	27	7.0	11	7.9
13	56	14	12	6.5
16	33	12	4.0	6.6
18	22	9	7.0	8.3
20	6.0	5.0	1.0	7.5
23	5.0	5.0	11	6.9
25	5.0	5.0	19	7.1

TABLE 14

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE F

(Sample F contained 60 pounds (27.3 kg) of perforated batteries buried in 160 pounds (72.7 kg) of Natick garden soil. 20 pounds (9.1 kg) of lime were dispersed over the batteries instead of being mixed with the soil.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	680	244	202	3.6
4	900	250	405	3.4
8	750	220	462	3.3
11	812	223	475	3.4
13	1,180	220	355	3.3
16	1,000	175	255	3.5
18	830	140	20	3.6
20	590	80	90	3.7
23	380	70	70	4.5
25	230	50	50	4.4

TABLE 15

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE G

(Sample G was an acid control and contained 5 pounds (2.3 kg) of tannic acid in 160 pounds (72.7 kg) of sand.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	0	108	38	3.8
4	0	160	130	3.7
8	0	160	154	3.6
11	0	165	193	3.7
13	0.9	125	145	3.7
16	0.8	75	75	3.8
18	0.5	60	70	3.7
20	1.0	25	50	4.0
23	0.6	25	45	4.1
25	0.4	20	45	4.2

TABLE 16

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE H

(Sample H contained perforated carbon-zinc batteries buried in an acid condition. 60 pounds (27.3 kg) of batteries were buried in 160 pounds (72.7 kg) of sand mixed with 5 pounds (2.3 kg) of tannic acid.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	2,000	680	164	3.4
4	1,700	1,100	1,100	3.2
8	2,500	1,062	2,312	3.2
11	5,000	1,062	2,688	2.7
13	5,000	910	4,750	2.7
16	5,000	780	4,250	2.7
18	4,750	650	3,750	2.2
20	2,500	520	1,500	2.8
23	3,000	530	1,750	2.9
25	2,750	480	1,500	3.0

TABLE 17

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE I

(Sample I was a base control and contained 20 pounds (9.1 kg) of lime mixed with 160 pounds (72.7 kg) of sand.)

Sample Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	0	0.5	0.4	5.4
4	0	0.4	0.2	5.5
8	0	0.4	0.5	5.6
11	0	0.5	0	6.9
13	0	0.4	0.2	6.4
16	0	0.2	0.1	6.8
18	0.1	0.1	0.1	6.7
20	0	0.1	0	7.0
23	0.3	0.1	0.1	6.8
25	0	0.1	0	6.7

TABLE 18

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE J

(Sample J contained 60 pounds (27.3 kg) of perforated batteries buried in 160 pounds (72.7 kg) of sand mixed with 20 pounds (9.1 kg) of lime.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	1,750	462	0	6.0
4	1,250	500	0	6.0
8	1,125	423	0.5	6.0
11	938	355	0	6.2
13	615	200	0	6.5
16	380	120	0	6.8
18	210	70	1.0	7.0
20	100	20	0	7.0
23	80	20	0.2	6.9
25	50	10	0.1	6.9

TABLE 19

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE K

(Sample K had 60 pounds (27.3 kg) of batteries buried in 160 pounds (72.7 kg) of sand, mixed with 20 pounds (9.1 kg) of lime.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	10.0	0.8	0.2	7.0
4	15.0	5.0	0	6.7
8	10.0	5.0	5.0	7.2
11	17.5	7.5	7.5	7.9
13	25	2.5	5.0	6.8
16	30	2.5	0.1	7.0
18	33	2.5	2.5	7.6
20	25	2.5	1.0	7.8
23	10	2.5	1.0	7.0
25	20	2.5	0.5	7.1

TABLE 20

ATOMIC ABSORPTION RESULTS FOR LEACHATE FROM SAMPLE L

(Sample L contained 60 pounds (27.3 kg) of batteries buried in 160 pounds (72.7 kg) of sand. 20 pounds (9.1 kg) of lime were dispersed over the batteries instead of being mixed with the sand.)

Elapsed Time (Weeks)	Concentrations			pH of Sample
	Zn (ppm)	Mn (ppm)	Fe (ppm)	
2	0	8.0	2.0	7.0
4	0	22.5	2.5	6.3
8	0	27.5	3.0	6.3
11	0	30.0	4.5	7.7
13	0.2	20	7.5	6.8
16	0	13	0	6.9
18	0.2	7.5	2.5	6.8
20	0	3.0	0	7.5
23	1.0	3.0	0	6.8
25	2.0	2.0	0.1	6.8